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WOOD-BASED PANELING AS THERMAL BARRIERS.(U)
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Wood-Based Paneling as Thermal Barriers

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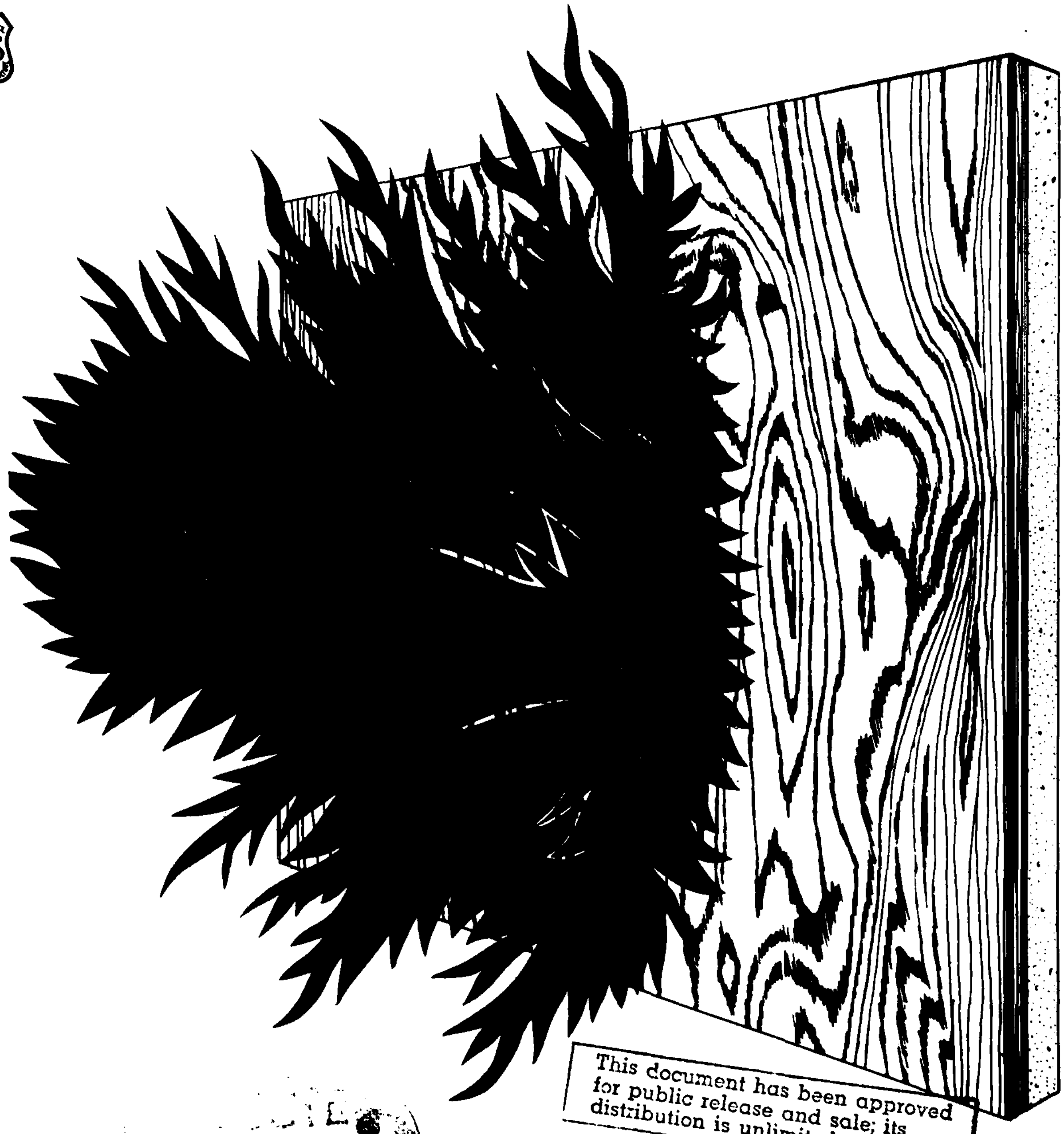

Abstract

Fire penetration tests were conducted to examine how the thermal protection afforded insulation in fire-exposed wall assemblies is influenced by wood-based panel type and thickness. Small-scale specimens (20-by 20-in.) were fabricated reflecting 1/4- to 3/4-inch plywood over 1-inch slabs of foam plastics; 5/8-inch plywood panels with no backup material, over a 3-1/2-inch loose-fill cellulosic insulation, 3-1/2-inch air gap, 1/2-inch foam plastic, or 3-1/2-inch glass-fiber insulation; and 5/8-inch particleboard, 5/8-inch hardboard composite, 5/8-inch solid wood, 5/8-inch fire-retardant-treated plywood or 1/2-inch gypsum wallboard over 1-inch slabs of foam plastic. These specimens were then subjected to the time-temperature fire exposure given in ANSI/ASTM Standard E 119.

Because this research was conducted only to characterize material response and not to define the more complex performance of full-scale assemblies according to all the requirements of ANSI/ASTM Standard E 119, the information is not directly applicable to establishing the "finish rating" for a given panel type. However, the results do increase our understanding of what panel characteristics influence "finish rating" in assemblies.

Acknowledgment

The author wishes to acknowledge the contribution of Ronald Knispel who conducted the fire penetration experiments. The author also thanks Koppers Company for providing the fire retardant-treated specimens.

Note:

Since completion of the tests reported in this paper, a small scale horizontal exposure furnace test for testing thermal barriers over a calcium silicate board was added to the Uniform Building Code. As a result, 1/2-inch thick gypsum wallboard specimens and 5/8-inch thick plywood specimens were tested over calcium silicate board substrates and foam plastic substrates in the FPL small scale vertical exposure furnace. In these tests, the differences in the mean values for the gypsum wallboard and the plywood were not significant. These results will be reported in a report, "Effect of Calcium Silicate Substrate on Thermal Barrier Results," by Robert H. White.

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Wood-Based Paneling as Thermal Barriers

By
ROBERT H. WHITE, Forest Products Technologist

Introduction

An interior finish on a wall, floor, or roof assembly provides thermal protection to the rest of the assembly when exposed to fire. This thermal protection is usually utilized to protect the load-bearing elements or to prevent the early involvement of certain combustible materials in a fire. The amount of protection provided is sometimes expressed in minutes as the finish rating (*10*)[2] or as the protective membrane performance (*1*). Both terms refer to the time at which the surface of the element being protected reaches an average temperature rise of 250° F or maximum temperature rise of 325° F as the assembly is subjected to the fire exposure specified in ANSI/ASTM E 119 (*1*). This condition will be called the 250°/325° F temperature criteria throughout this report.

In recent years, building codes have required foam plastics to be fully protected from the interior of the building by a thermal barrier of fire-resistive materials having a finish rating of not less than 15 minutes. A 1/2-inch Type X gypsum board is the only material specifically regulated by these model codes for composition and installation that qualifies (*8*). However, building codes suggest that standard 1/2-inch gypsum board can also provide adequate thermal protection to foam plastic insulation. Because they wish to use a wood-based interior finish, inquirers have asked the U.S. Forest Products Laboratory (FPL) to investigate parameters influencing the thermal barrier performance of wood.

In response, FPL scientists conducted fire penetration tests to determine how the thermal protection provided fire-exposed assemblies varies with type and thickness of wood-based panels. Two heat transfer analyses were also used to obtain theoretical estimates of the performance of the wood-based panels. Building code specific performance requirements for a thermal barrier require the finish rating to be determined by conditions specified in the ANSI/ASTM E 119 standard (*1*) test procedure. Cases not meeting the specific requirements may be individually accepted based on other diverse tests approved by the building code official. The acceptability of some of these tests is controversial (*3,9*).

Determining the protective membrane performance according to ANSI/ASTM E 119 requires testing 100-square foot (ft^2) wall assemblies, or 180-ft^2 floor and roof assemblies. Testing of such large-scale assemblies was not practical for the more limited purposes of this study. Therefore, 2.8-ft^2 specimens were evaluated only to determine how a panel's thermal performance is influenced by characteristics of the material used. For example, no determination was made as to how long a full-size membrane would stay in place nor was the performance of joints a factor as they are in large-scale tests. Because of the differences in test scale and interpretation, the results in this

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Italicized numbers in parentheses refer to literature cited at the end of report.

report do not necessarily reflect the finish rating for the protective membrane of a full-scale assembly.

Research Method

The specimens were tested in the FPL small vertical furnace (fig. 1) and included panels of different thickness over 1-inch slabs of foam plastic and 5/8 inch thick plywood over other types of insulation (table 1). The specimens were subjected to fire exposure on one face until the 250°/325° F temperature criteria of ANSI/ASTM E 119 were satisfied. Two or three replicates of each type of specimen were tested. For most of the tests, the specimens were conditioned at 80° F, 30 percent relative humidity (RH), a conditioning that has traditionally been used for FPL fire tests. The resulting 6 percent equilibrium moisture content in wood is the lowest recommended average moisture content for interior use of wood products in the United States (*12*). For most of the country, the recommended average moisture content for interior use of wood products is 8 percent (*12*). The ANSI/ASTM E 119 standard specifies 73° F, 50 percent RH conditioning with an equilibrium moisture content of 9 percent (*1*). Equilibrium moisture content for the 80° F, 65 percent RH conditioning is 12 percent.

Specimens

The author used three variations of specimen construction:
(1) Specimens with a panel over a slab of foam plastic had the 20- by 20-inch panel and the foam plastic nailed to a wood frame with three upright members (figs. 1 and 2). (2) Specimens with air gap, glass-fiber, or cellulosic insulation had no center upright member in the frame; the frame side not exposed to fire was covered with 3/8-inch plywood. (3) Specimens with no insulation had the plywood tested without a wood frame.

Six thermocouples were located at the fire-exposed, panel-insulation interface. Five were attached to the unexposed panel side with 3-inch square pieces of duct tape. Thermocouples were positioned at the center of the panel and at the center of each quadrant. The sixth thermocouple was attached at the center of the fire-exposed side of the insulation (or vapor barrier). On the unexposed side of the assembly, two thermocouples were placed beneath 3-inch square asbestos pads (fig. 1). All thermocouples were 30-gage iron-constantan.

Materials

The untreated plywood, hardboard, and gypsum wallboard were obtained from commercial sources as 4- by 8-foot sheets. Starting at one corner, eight 20- by 20-inch specimens were cut from each sheet. Random numbers were used to select the specimen to be used in each test. The particleboard and solid wood specimens were cut from materials left over from previous studies. The 20- by 20-inch specimens of fire-retardant treated (FR) plywood were supplied by a commercial treater.

Figure 1.—Test specimens and FPL small vertical furnace.

(M 147593-9)

Southern pine (SP) plywoods were graded as exterior BC, species group 1. The 1/4-, 3/8-, 1/2-, 5/8-, and 3/4-inch panels had 3, 3, 4, 5, and 5 plies, respectively, all which were southern pine (*Pinus* sp.).

Mixed species (MS) plywoods were graded as exterior AC, species group 1. The 5/8-inch mixed species plywood had face plies, two cross plies, and a center ply of Douglas-fir (*Pseudotsuga menziesii*), aspen or cottonwood (*Populus* sp.), and a western yellow pine (*Pinus* sp.), respectively. The 3/4-inch mixed species plywood had face plies and two cross plies that were Douglas-fir (*Pseudotsuga menziesii*) and a center ply of spruce (*Picea* sp.).

Particleboard was a commercial floor-underlayment particleboard made from southern pine (*Pinus* sp.) and urea-formaldehyde adhesive.

Table I.—Description of specimens tested in small vertical furnace

Specimen Number	Specimen code[1]	Panel				Insulation	
		Type[2]	Approximate thickness	Conditioning		Type	Approximate thickness
			In.	°F	Pct RH		In.
1	SP1/4- 6-F	SP plywood	1/4	80	30	Foam plastic	1
2	SP3/8- 6-F	SP plywood	3/8	80	30	Foam plastic	1
3	SP1/2- 6-F	SP plywood	1/2	80	30	Foam plastic	1
4	SP5/8- 6-F	SP plywood	5/8	80	30	Foam plastic	1
5	SP3/4- 6-F	SP plywood	3/4	80	30	Foam plastic	1
6	MS5/8- 6-F	MS plywood	5/8	80	30	Foam plastic	1
7	MS3/4- 6-F	MS plywood	3/4	80	30	Foam plastic	1
8	PB5/8- 6-F	Particleboard	5/8	80	30	Foam plastic	1
9	HB5/8- 6-F	Hardboard	5/8	80	30	Foam plastic	1
10	SW5/8- 6-F	Solid wood	5/8	80	30	Foam plastic	1
11	FR5/8- 6-F	FR plywood	5/8	80	30	Foam plastic	1
12	SP3/4- 0-F	SP plywood	3/4	ovendry		Foam plastic	1
13	SP3/4- 9-F	SP plywood	3/4	73	50	Foam plastic	1
14	MS3/4- 9-F	MS plywood	3/4	73	50	Foam plastic	1
15	MS5/8- 9-F	MS plywood	5/8	73	50	Foam plastic	1
16	MS5/8-12-F	MS plywood	5/8	80	65	Foam plastic	1
17	SP5/8- 6-F/2	SP plywood	5/8	80	30	Foam plastic	1/2
18	SP5/8- 6-N	SP plywood	5/8	80	30	None	—
19	SP5/8- 6-A	SP plywood	5/8	80	30	Air gap	3-1/2
20	SP5/8- 6-G	SP plywood	5/8	80	30	Glass-fiber	3-1/2
21	SP5/8- 6-C	SP plywood	5/8	80	30	Cellulosic	3-1/2
22	GY1/2-30-F	Gypsum	1/2	80	30	Foam plastic	1
23	GY1/2-65-F	Gypsum	1/2	80	65	Foam plastic	1

[1] Specimen code indicates type and thickness of panel, equilibrium moisture content (relative humidity in the case of gypsum), and type of insulation.

[2] SP = southern pine, MS = mixed species, FR = fire-retardant treated.

Hardboard was a composite consisting of two 1/4-inch and one 1/8-inch layers of a commercial tempered hardboard of unknown composition. The layers were glued together with phenol resorcinol adhesive.

Solid wood specimens were made from 20-inch long boards cut from 5-inch wide planks of southern pine (*Pinus* sp.). The boards were glued together (plain side-to-side grain joints) with phenol-resorcinol adhesive to make a 20-inch wide specimen. A different plank was used for each of the three specimens. Ovendry densities of the planks were 42.4, 34.3, and 39.2 lb/ft^3 for the first, second, and third specimens tested, respectively.

Fire-retardant-treated (FR) plywood was graded C-D interior with exterior glue and had been fire-retardant treated with an Underwriters Laboratories classified commercial pressure treatment. The density as tested was about 38 lb/ft^3. The four plies were southern pine (*Pinus* sp.).

Gypsum board was a regular gypsum wallboard. The densities as tested were 43.3 ± 1.5 lb/ft^3 and the actual thicknesses of the gypsum board specimens were 0.496 ± 0.004 inch.

Glass-fiber insulation had a batt of glass-fiber with kraft and standard foil facing on the fire-exposed side. Glass-fiber density was about 0.6 lb/ft^3; the 3.5-inch-thick batt had a thermal resistance R-factor of 11° F·h·ft^2/Btu.

Cellulosic insulation was a loose-fill wood fiber derived from newsprint. The fire-retardant-treated insulation had an R-factor of 13° F·h·ft^2/Btu for the 3.5-inch thickness and settled density of 2.7 lb/ft^3. A plastic vapor barrier was installed on the fire-exposed side of the insulation.

Foam plastic insulation had a glass-reinforced polyisocyanurate foam plastic core with aluminum foil facings. The 1-inch-thick sheathing had an R-factor of 7.2° F·h·ft^2/Btu and a density of 2 lb/ft^3.

Test Procedure

The vertical furnace (fig. 1) has a 20-inch square opening on its side into which the assembly was inserted. The furnace is equipped with pipe outlets for discharg-

Figure 2.—Specimen with plywood and plastic foam sheathing nailed to a wood frame.
(M 147688)

ing natural gas into the furnace. All air for combustion was admitted by natural draft through vents at the bottom of the furnace with baffling to get proper distribution. Inside the furnace, a single iron-capped thermocouple was located opposite the center of the panel and 2-inches from the exposed surface of the panel. This is closer placement than the 6 inches specified in ANSI/ASTM E 119 (*1*). The gas supply of the furnace was regulated by monitoring the iron-capped thermocouple so that the temperature followed the ANSI/ASTM E 119 time-temperature curve (*1*). Temperatures on this curve are 1,000°, 1,300°, and 1,399° F at 5, 10, and 15 minutes, respectively. Recorders monitored the temperatures indicated by the various thermocouples during the tests.

Theoretical Analyses

Predictions of times for the 250°/325° F criteria given in ANSI/ASTM E 119 were made using two theoretical procedures. The first procedure was the Aerotherm Corporation Charring Material Thermal Response and Ablation (CMA) computer program (*13*). The CMA computer program is an implicit finite-difference computational procedure for describing the one-dimensional thermal behavior of a two-sided ovendried slab that can ablate on one surface and decompose in depth. The surface temperature and surface recession rate are specified in the boundary condition option used in this study.

The second procedure was a computer program for the thermal analysis of the fire endurance of construction walls (FDCW) (*4*). The FDCW computer program is a finite-difference computational procedure for one-dimensional heat transfer in which heat transfer occurs by conduction through solids, and by radiation and convection through air spaces. For each solid layer the program includes phase changes with heat generation or absorption (e.g. vaporization of water).

The computer programs required the input of a number of parameters. Selection of values for the input parameters was based on experimental measurements, literature data, and previous experience with the computer programs. Details on the input for the CMA computer program are given in a previous publication (*13*). The property subroutine in FDCW (*4*) was modified to account for effect of moisture content on thermal properties at temperatures below 221° F and for char properties at temperatures above 550° F.

Measurements were made to obtain data for thickness, ovendry wood density, char density, moisture content, thermal conductivity, and surface recession (table 2) of the wood-based panels. It is likely that the mass in a piece of char is from a volume of wood greater than the volume of the piece of char. Because the CMA program assumes that the change from wood to char density is due only to a mass change, a reduction in the measured char density is necessary. Data for char density were arbitrarily reduced by 50 percent to levels in agreement with previous experience with the CMA computer program. Data for the different panels of untreated southern pine plywood (specimen Nos. 1-5, 12-13, 17-21) were averaged to obtain the input values for char density/wood density ratio, thermal conductivity, and surface recession. Single ANSI/ASTM C 518 (*2*) thermal conductivity tests were conducted on each of the different panel materials. For the FDCW analyses, the heat of absorption was the product of the heat of vaporization of water 970 Btu/lb, the ovendry wood density, and the fractional moisture content.

Input values for the insulation was based on data in the literature. The thin foil on the foam plastic insulation or glass-fiber insulation was not included in the analyses. For the CMA analyses, the convection heat transfer coefficient at the unexposed back surface was 0.44 Btu/h·ft^2·°F.

Experimental Results and Discussion

The 250°/325° F temperature increase criteria were satisfied after 2.6 to 15.8 minutes of ANSI/ASTM E 119 fire exposure (table 3). Results for the different wood-based specimens tested depended on the thickness, species, density, fire-retardant treatment, and moisture content of the panel, and on the presence of insulation behind the panel. The influence of each of these parameters on the response are discussed in the following paragraphs.

Panel Thickness

As plywood thickness tested (6 pct moisture content) was increased, time periods until the temperature criteria were satisfied increased linearly (fig. 3). Assuming a straight line through the data points (specimen Nos. 1 to 5), the increase was 20.5 minutes per inch thickness. The linear correlation coefficient for the data (fig. 3) was very high (0.995). The average results for the 5/8- and 3/4-inch untreated southern pine plywood (specimen Nos. 4 and 5) were 10.2 and 12.1 minutes, respectively.

Table 2.—Input parameters of panels for theoretical analysis of assemblies

Specimen No.	Specimen code[1]	Thickness	Wood density[2]	Char density[3]	Moisture content	Thermal conductivity[4]	Surface recession
		In.	Lbs/ft³	Lbs/ft³	Pct	Btu. in / ft² hr °F	In./hr
1	SP1/4- 6-F	0.26	33.3	9.6	5.8	0.79	0.73
2	SP3/8- 6-F	.36	31.6	9.2	5.6	.79	.73
3	SP1/2- 6-F	.49	33.5	9.7	5.6	.79	.73
4	SP5/8- 6-F	.62	36.4	10.6	5.2	.79	.73
5	SP3/4- 6-F	.73	32.0	9.3	5.4	.79	.73
6	MS5/8- 6-F	.61	30.5	8.8	4.4	.62	.43
7	MS3/4- 6-F	.73	29.3	8.5	4.6	.67	.03
8	PB3/8- 6-F	.62	46.2	12.4	6.0	.84	.59
9	HB5/8- 6-F	.61	60.0	17.9	4.5	.82	.59
10	SW5/8- 6-F	.62	38.6	13.2	6.9	.80	.87
11	FR5/8- 6-F	.63	36.0	13.9	6.4	.91	.55
12	SP3/4- 0-F	.73	32.2	9.4	0.0	.79	1.20
13	SP3/4- 9-F	.74	32.0	[5]—	7.9	.79	[5]—
14	MS3/4- 9-F	.74	30.0	[5]—	7.0	.67	[5]—
15	MS5/8- 9-F	.61	29.7	[5]—	6.0	.62	[5]—
16	MS5/8-12-F	.61	29.2	[5]—	8.7	.62	[5]—
17	SP5/8- 6-F12	.61	36.7	10.6	5.6	.79	.73
18	SP5/8- 6-N	.62	36.7	10.6	5.2	.79	.73
19	SP5/8- 6-A	.61	37.6	10.9	5.0	.79	.73
20	SP5/8- 6-G	.61	37.5	10.9	5.0	.79	.73
21	SP5/8- 6-C	.61	36.7	10.6	5.2	.79	.73

[1] Specimen code indicates type and thickness of panel, equilibrium moisture content, and type of insulation. (See table 1)

[2] Based on ovendry weight and volume at moisture content of test.

[3] For FDCW analyses, char density was 29 pct of wood density for all specimens.

[4] At temperature of 75° F, temperature correction based on ratio of absolute temperatures.

[5] No CMA analysis performed due to high moisture content.

The 10.0 minutes average result for the 5/8-inch mixed species plywood (specimen No. 6) was close to the southern pine plywood result (specimen No. 4). This mixed species plywood had thin faces of Douglas-fir but was mostly western yellow pine and aspen/cottonwood. The average result for the 3/4-inch mixed species plywood (specimen No. 7) was 14.0 minutes or 1.9 minutes greater than for the southern pine plywood (specimen No. 5). A t-test of the data for specimen Nos. 5 and 7 indicated that the difference in the means was significant at the 5 percent level. For the specimens conditioned at 50 percent RH (specimen Nos. 13 and 14), the difference of the means for the 3/4-inch southern pine plywood (13.8 min) and the 3/4-inch mixed species plywood (15.6 min) was significant at the 10 percent level. The 3/4-inch mixed species plywood was Douglas-fir except for a center ply of spruce. Thus, times for the 250°/325° F criteria may be dependent on the species of the plies. Unfortunately, current species identification of plywood is based only on the face plies and only the species group is noted in the grade marks. All of the plywood tested were graded as species group 1.

The 2.7 and 10.2 minute average results for the 1/4- and 5/8-inch southern pine plywood (specimen Nos. 1 and 4) were considerably less than previously reported results (*11*). These older results were for tests conducted in 1937 in which 1/4- and 5/8-inch phenolic resin, Douglas-fir plywood had times of 6 and 16 minutes, respectively. In the latest series of tests ignition of the plywood panel occurred about 0.8 minute after the start of the test. In the 1937 tests, ignition of the panels occurred about 4.0 minutes after the start of the test. The difference in the ignition times is probably due to differences in the testing procedures. In the 1937 tests the furnace was preheated before the beginning of the test. In the latest series of tests, the normal practice of having the furnace at room temperature at the beginning of the test was followed. Subtraction of the difference in ignition times would reduce the 1937 results to 2.8 and 12.8 minutes for the 1/4- and 5/8-inch plywood, respectively. The remaining difference in the results may be due to the fact that the 1937 plywood specimens were fabricated in the laboratory with only Douglas-fir plies. Also, the moisture content of the 1937 specimens was not recorded.

Table 3.—Time until 250°/325° F temperature criteria were satisfied on exposed side of the panel[1]

Specimen No.	Specimen code[2]	Test No. 1	Test No. 2	Test No. 3	Mean	Standard deviation	Coefficient of variation
		Min					Pct
1	SP1/4- 6-F	2.7	2.7	2.6	2.67	0.06	2.2
2	SP3/8- 6-F	4.4	4.4	4.4	4.38	.01	0.2
3	SP1/2- 6-F	7.1	6.8	6.7	6.87	.21	3.0
4	SP5/8- 6-F	10.1	10.0	10.4	10.17	.21	2.0
5	SP3/4- 6-F	12.0	11.8	12.5	12.10	.36	3.0
6	MS5/8- 6-F	10.0	9.6	10.3	9.97	.35	3.5
7	MS3/4- 6-F	14.1	13.6	14.3	14.00	.36	2.6
8	PB5/8- 6-F	14.0	13.3	13.9	13.73	.38	2.8
9	HB5/8- 6-F	14.2	13.7	14.3	14.07	.32	2.3
10	SW5/8- 6-F	11.3	10.5	11.6	11.13	.57	5.1
11	FR5/8- 6-F	11.3	11.0	—	11.15	.21	1.9
12	SP3/4- 0-F	8.8	8.5	—	8.65	.21	2.4
13	SP3/4- 9-F	14.0	13.7	—	13.85	.21	1.5
14	MS3/4- 9-F	15.8	15.4	—	15.60	.28	1.8
15	MS5/8- 9-F	10.6	10.5	—	10.55	.07	0.7
16	MS5/8-12-F	12.3	12.6	—	12.45	.21	1.7
17	SP5/8- 6-F12	11.0	10.4	10.6	10.67	.31	2.9
18	SP5/8- 6-N	11.2	11.6	11.7	11.50	.26	2.3
19	SP5/8- 6-A	10.4	10.0	10.9	10.43	.45	4.3
20	SP5/8- 6-G	9.6	9.5	10.0	9.70	.26	2.7
21	SP5/8- 6-C	10.1	10.4	10.7	10.40	.30	2.9
22	GY1/2-30-F	12.8	11.6	14.4	12.93	1.40	10.8
23	GY1/2-65-F	14.8	15.4	—	15.10	.42	2.8

[1] The 250° F plus initial limit on average temperature was the criterion except for tests 1 and 2 of specimen Nos. 22 and 23 (gypsum). For all the tests the difference between the times for the two criteria was 1.3 minutes or less.

[2] Specimen code indicates type and thickness of panel, equilibrium moisture content, or relative humidity (gypsum), and type and thickness of insulation. (See table 1)

The 6.9 minute average result for the 1/2-inch southern pine plywood is also less than published results for 1/2-inch Douglas-fir plywood. In similar tests using an electric furnace heated with silicon carbide elements, it took 11.5, 10.5, and 12.0 minutes for a polystyrene foam and 10.5, 10.0, and 11.0 minutes for a polyurethane foam, respectively, to reach an average temperature rise of 250° F at the interface of plastic foam and 1/2-inch Douglas-fir plywood protection (6). During these tests, flames were observed in the furnace chamber about 4 minutes after start when the conditioning prior to testing was 70° F and 50 percent RH. Again, time differences appear due to differences in testing procedures (e.g., electric heating elements versus natural gas) and the difference in conditioning of the plywood.

Panel Density

Results for the 5/8-inch plywood, particleboard, hardboard, and solid wood (specimen Nos. 4, 6, 8, 9, and 10) involved a range of densities. Based on a linear regression (fig. 4), the data indicate an increase of 0.156 minute to the times for the 250°/325° F criteria per unit (lb/ft³) increase in the density. The linear correlation coefficient for the regression again was high (0.90).

Results obtained for the hardboard composite are probably low for its density level since the char tended to fall away at the gluelines of the layers.

In previous tests of one-ply specimens of four types of 1/2-inch structural flakeboards (5), the times for the 250°/325° F temperature rise ranged from 10.2 to 13.0 minutes. The average result for the 1/2-inch southern pine plywood (specimen No. 3) was 6.9 minutes. In the flakeboards tests there was no insulation behind the panel but the thermocouples were under asbestos pads. The flakeboards had densities of 40 to 46 lb/ft³ and the flakes were Douglas-fir, aspen, or a mixture of western species.

Fire-Retardant Treatment

The average result for the C-D FR plywood (specimen No. 11) was 1 minute greater than the result for the untreated B-C plywood (specimen No. 4). A t-test comparison of the data for these specimens indicated that the difference in the means was significant at the 5 percent level. Differences between the two plywoods unrelated to the fire-retardant treatment, such as the grade of the plywood, may have affected the results. These results showing a slight improvement for the FR

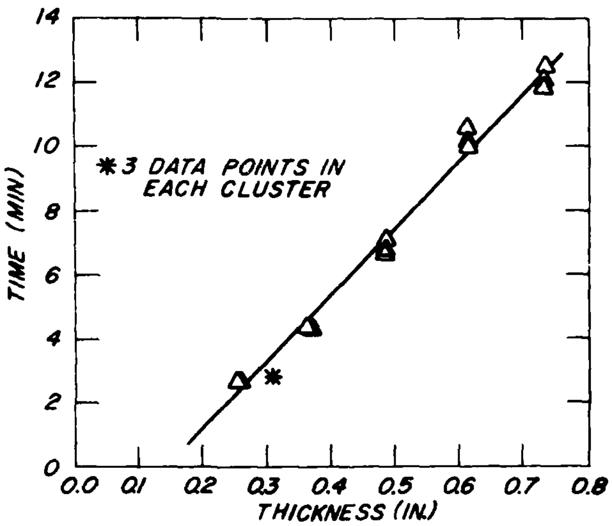

Figure 3.—Thicker panels of southern pine plywood required longer times to achieve the 250°/325° F criteria.

(M 149891)

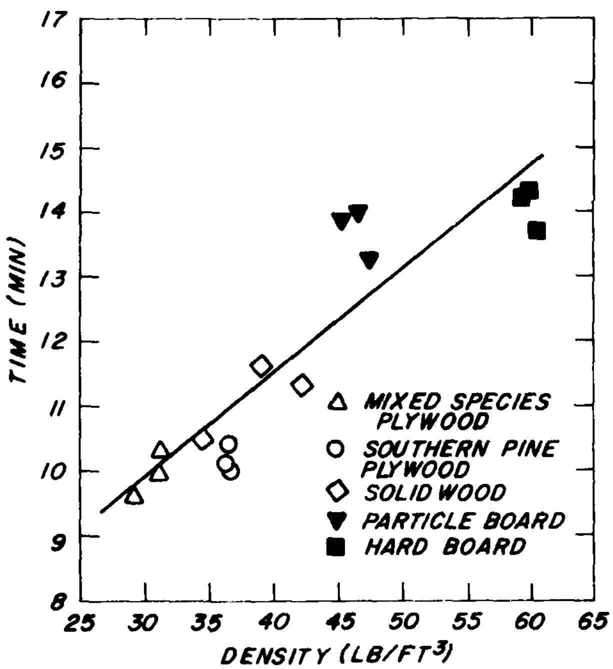

Figure 4.—Denser 5/8-inch panels required more time to reach the 250°/325° F criteria.

(M 149892)

plywood are consistent with previous test data (7). In 1937, five 24- by 24-inch specimens of 3/8-inch three-ply plywood were tested in a small vertical furnace. The plywoods were a composite of untreated plies and plies impregnated by a hot and cold method using a solution of ammonium sulfate and monoammonium phosphate. The 250° F temperature rise results ranged from 8.0 to 9.0 minutes, depending upon which of the plies were treated.

Panel Moisture Content

The 5/8-inch mixed species plywood (specimen Nos. 6, 15, and 16), the 3/4-inch southern pine plywood (specimen Nos. 5, 12, and 13) and the 3/4-inch mixed species plywood (specimen Nos. 7 and 14) were tested after conditioning to a range of moisture contents. Assuming a linear relationship (fig. 5), the data indicate that increasing the percentage moisture content by 1 increases the times of the 250°/325° F criteria by an average 0.63 minute. Linear correlation coefficients of the regressions were 0.95 or greater. The moisture contents (ovendry method) of the plywoods were lower than the equilibrium moisture contents normally obtained with wood at the different conditionings.

Insulation

While the presence of insulation behind the panel had an effect on the times needed to achieve the 250°/325° F criteria, there is a considerable overlapping of the 95 percent confidence intervals (table 4). The average 11.5 minute result for the 5/8-inch southern pine plywood without any insulation (specimen No. 18) was significantly greater (5 pct level) than results for the plywood with insulation of 9.7 to 10.7 minutes (specimen Nos. 4, 17, 19, 20, and 22). The 11.5 minutes result (specimen No. 18) is based on thermocouples attached to the unexposed side of the panel with duct tape. In these tests, four additional thermocouples were under asbestos pads on the unexposed side. The average 250°/325° F result for these thermocouples was 10.2

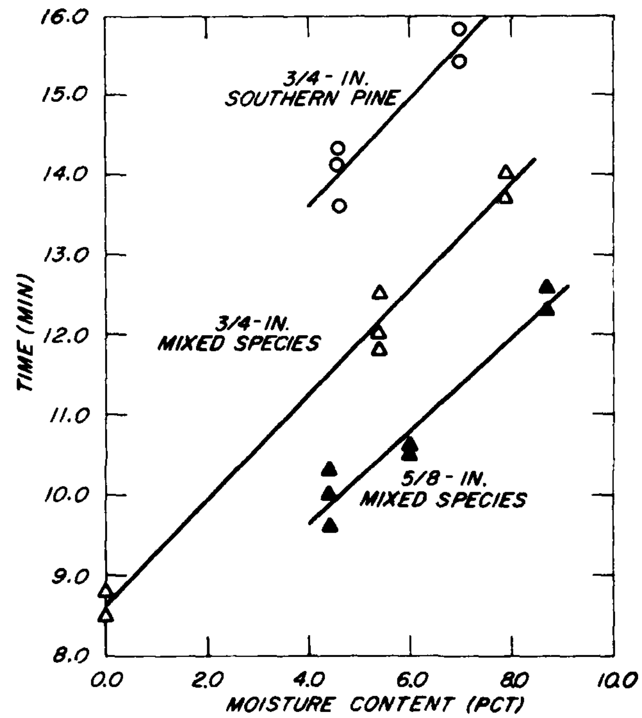

Figure 5.—An increase in the moisture increased the times for three plywood panels to reach the 250°/325° F criteria.

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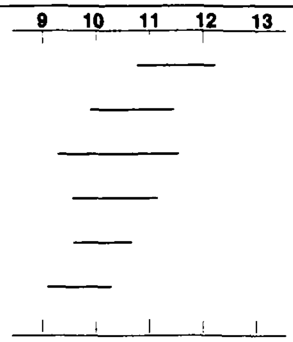
Table 4.—Confidence intervals (95 pct) for the test of 5/8-inch southern pine plywood over different types of insulation. (Based on three tests of each specimen)

Insulation type	Specimen No.	Mean (Min)	95 Percent confidence interval (Min)
None	18	11.5	
1/2-in. Foam Plastic	17	10.7	
3-1/2-in. Air Gap	19	10.4	
3-1/2-in. Cellulosic	21	10.4	
1/2-in. Foam Plastic	4	10.2	
3-1/2-in. Glass-Fiber	20	9.7	



minutes, significantly different (5 pct level) than the result for the thermocouples under the duct tape and in general agreement with the results for the panels with insulation. The use of asbestos pads on the unexposed side of test specimens is specified in ANSI/ASTM E-119 (*1*). These tests illustrate the influence of such pads on heat accumulation at the surface of the panels.

A t-test comparison among the specimens with insulation indicates that the mean result for the glass-fiber (specimen No. 20) is significantly less than the mean result for the 1/2-inch foam plastic (specimen No. 17) at the 5 percent level. Differences between the means for the 1-inch foam plastic, 1/2-inch foam plastic, air gap, and cellulosic specimens (specimen Nos. 4, 17, 19, and 21) were not significant at the 5 percent level. Correlations of the results with insulation values (R-factors) were inconclusive.

In the cellulosic insulation tests, water vapor from the plywood may have been trapped by the plastic vapor barrier. The presence of a gap between the vapor barrier and the plywood was indicated by the large difference in times recorded for the thermocouple on the cool side of the plywood and times recorded for the thermocouple on the hot side of the insulation. This difference for the cellulosic tests was 0.5 to 1.8 minutes versus 0.6 minute or less for the other specimens. The gap may have increased the 250°/325° F times for the cellulosic insulation-backed specimens.

Gypsum Wallboard

Average results for the 1/2-inch regular gypsum board were 12.9 minutes for those conditioned at 80° F and 30 percent RH (specimen No. 22) and 15.1 minutes for those conditioned at 80° F and 65 percent RH (specimen No. 23). The gypsum board normally failed due to the transfer of heat through cracks that developed in the panels during the fire exposure. The difference of 2.2 minutes in the means for the two conditionings was not significant at the 10 percent level.

Statistical comparison of times for the 250°/325° F criteria and densities of the panels as tested indicated that the variation in times was mainly due to differences in the densities. Differences in the thicknesses were minimal and not factors in the results. Variation in the total density could have been due to differences in the dry mass, the chemically combined water, and the absorbed water components of the density.

Due to the higher variability of the regular gypsum board (conditioned at 80° F, 30 pct RH), the results for a number of the wood-based panels (conditioned at 27° C, 30 pct RH) were within the 95 percent confidence interval of the gypsum board (table 5). In t-test comparisons of all 5/8- and 3/4-inch wood-based panel results (specimen Nos. 4 to 11) with the gypsum board results (specimen No. 22), the differences in the means were not significant at the 5 percent level. However, the means for both of the 5/8-inch untreated plywoods (specimen Nos. 4 or 6) were significantly less, by about 3.0 minutes, than that for the gypsum board at the 10 percent confidence level. In a similar fashion, a difference of 2.7 minutes was significant at the 10 percent level for the 5/8-inch mixed species plywood (specimen No. 16) and the gypsum board (specimen No. 23) conditioned at 80° F and 65 percent RH.

In similar tests using an electric furnace heated with silicon carbide elements, it took 16.0, 15.0, and 16.5 minutes for polystyrene foam and 14.5, 15.0, and 14.5 minutes for polyurethane foam, respectively, to reach an average temperature rise of 250° F at the interface of plastic foam and 1/2-inch regular gypsum board protection (*6*). Conditioning before tests was 70° F and 50 percent RH.

Theoretical Prediction Results and Discussion

The theoretical predictions were substantially different than the experimental results (table 6). Except for the

Table 5.—Comparison of 95 percent confidence intervals for the 5/8-inch and 3/4 inch wood-based panels with the interval for the 1/2-inch regular gypsum board (80° F, 30 pct RH conditioning). (Based on two tests of specimen No. 11, and three tests of rest of specimens.)

Panel type	Specimen No.	Mean (Min)	95 percent confidence interval (Min)
5/8-in. Hardboard Composite	9	14.1	
3/4-in. MS Plywood	7	14.0	
5/8-in. Particleboard	8	13.7	
1/2-in. Gypsum Board	22	12.9	
3/4-in. SP Plywood	5	12.1	
5/8-in. FR Plywood	11	11.2	
5/8-in. Solid Wood	10	11.1	
5/8-in. SP Plywood	4	10.2	
5/8-in. MS Plywood	6	10.0	

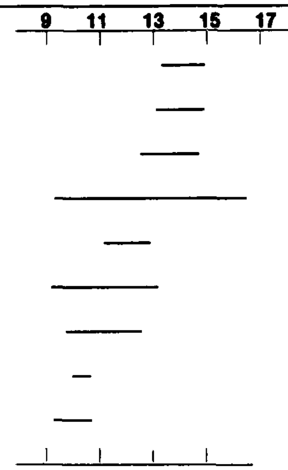


Table 6.—Predictions of the times to reach the 250°/325° F temperature criteria for the wood-based panels

Specimen No.	Specimen code[1]	Average experimental result	CMA[2] prediction	Error	FDCW[3] prediction	Error
		Min	Min	Pct	Min	Pct
1	SP1/4- 6-F	2.67	2.95	+10.5	5.14	+92.5
2	SP3/8- 6-F	4.38	3.95	−9.8	6.97	+59.1
3	SP1/2- 6-F	6.87	5.50	−19.9	9.92	+44.4
4	SP5/8- 6-F	10.17	7.70	−24.3	13.37	+31.5
5	SP3/4- 6-F	12.10	8.81	−27.2	15.28	+26.3
6	MS5/8- 6-F	9.97	7.66	−23.2	12.77	+28.1
7	MS3/4- 6-F	14.00	9.08	−35.1	15.11	+7.9
8	PB5/8- 6-F	13.73	7.95	−42.1	16.66	+21.3
9	HB5/8- 6-F	14.07	10.32	−26.6	18.54	+31.8
10	SW5/8- 6-F	11.13	8.47	−23.9	15.40	+38.4
11	FR5/8- 6-F	11.15	8.04	−27.9	14.61	+31.0
12	SP3/4- 0-F	8.65	8.61	-0.5	11.59	+34.0
13	SP3/4- 9-F	13.85	[4]8.81	-36.4	18.20	+31.4
14	MS3/4- 9-F	15.60	[5]9.08	-41.8	18.31	+17.4
15	MS5/8- 9-F	10.55	[6]7.66	-27.4	13.69	+29.8
16	MS5/8-12-F	12.45	[6]7.66	-38.5	16.01	+28.6
17	SP5/8- 6-F12	10.67	7.48	−29.9	14.48	+35.7
18	SP5/8- 6-N	11.50	8.82	−23.3	16.36	+42.3
19	SP5/8- 6-A	10.43	7.91	−24.2	16.16	+54.9
20	SP5/8- 6-G	9.70	7.54	−22.2	14.99	+54.5
21	SP5/8- 6-C	10.40	7.62	−26.7	16.96	+63.1

[1] Specimen code indicates type and thickness of panel, equilibrium moisture content, and type and thickness of insulation

[2] Aerotherm Corporation Charring Material Thermal Response and Ablation computer program (*13*).

[3] Computer program for the thermal analysis of the fire endurance of construction walls (*4*).

[4] Same as specimen No. 5.

[5] Same as specimen No. 7.

[6] Same as specimen No. 6.

1/4-inch plywood, the CMA predictions were 0.5 to 42 percent lower than the experimental results and the FDCW predictions were 8 to 63 percent higher than the experimental results. For the 1/4-inch plywood (specimen No. 1), both procedures overestimated the resistance times.

Linear regression was used to evaluate the variation of the results listed in table 4 with the changes in the three parameters of thickness, density, and moisture content (table 7). For a unit increase in either thickness, density, or moisture content of the plywood, the increase in times for the 250°/325° F criteria based on the theoretical predictions were in general agreement with the experimental results. Neither the CMA or FDCW results indicated the 1.9 minute difference between the two 3/4-inch plywoods (specimen Nos. 5 and 7). The rankings of the 5/8-inch plywood specimens with different insulation types (specimen Nos. 4, 17- 21) by the experimental results and the two sets of predicted results were inconsistent.

CMA predictions were low primarily because the CMA procedure does not consider the influence of phase change or transfer of moisture in the material. During the tests, the temperature rise in the panels was delayed due to the heat absorption associated with moisture vaporization. For the ovendry plywood (specimen No. 12), the CMA prediction was within 1 percent of the average experimental result.

The FDCW predictions were high probably because the FDCW procedure does not consider the recession of the char at the surface. In the case of the 3/4-inch southern pine plywood (specimen No. 5), the thicknesses of the panels after about 13 minutes were 25 percent less than the initial thickness. The error for the FDCW prediction was 26 percent for specimen No. 5. Very little surface recession was recorded in the tests of the 3/4-inch mixed species plywood (specimen No. 7). The error for the FDCW prediction for specimen No. 7 was an acceptable 8 percent. Heat generation/absorption associated with thermal decomposition may also be responsible for some of the FDCW error.

The results for both procedures are dependent upon the values used to define the boundary conditions and the material properties. The FDCW predictions probably would have been different if the published property subroutine (*4*) had been used. In using these programs to predict the behavior of thermal barriers, there is likely to be a range of reasonable values for the input parameters.

Summary

The thermal barrier performance of a wood-based paneling will be dependent upon a number of panel material characteristics. Increasing density, moisture content, and thickness of a panel were found to significantly increase the times to achieve the 250°/325° F rise in the temperature on the unexposed face of the panel. The change was linear for the panel properties range used. The species of the wood probably had an effect as well on the resistance times. A slight increase in the times was observed in the tests of fire-retardant-treated plywood when compared to un-

Table 7.—Variation of the times to reach the 250°/315° F temperature criteria with changes in three parameters[1]

Parameter	Units	Specimen Nos.	Increase in times until 250°/325° F temperature criteria per unit increase in parameter		
			Experimental results	CMA[2] predictions	FDCW[3] predictions
			Min		
Thickness	In	1-5	20.5	13.0	22.4
Density	lbs/ft^3	4,6,8-10	.16	.08	.19
Moisture content	Pct	[4]5,12,13	.655	NA[7]	.812
		[5]7,14	.667	NA[7]	1.333
		[6]6,15,16	.590	NA[7]	.764

[1] Based on linear regression of results listed in table 4, and data in table 2.

[2] Aerotherm Corporation Charring Material Termal Response and Ablation computer program (*13*).

[3] Computer program for the thermal analysis of the fire endurance of construction walls (*4*).

[4] 3/4-inch southern pine plywood.

[5] 3/4-inch mixed species plywood.

[6] 5/8-inch mixed species plywood.

[7] Not applicable.

treated material. The presence of insulation behind the panel reduced the times to achieve a 250°/325° F rise in temperature.

Since the fire resistance of some materials is very dependent upon the conditioning (temperature, relative humidity) of the material, the evaluation of materials depends upon what conditioning is employed. The response of a majority of panels was evaluated after 80° F, 30 percent RH conditioning. This is a level in wood base panels more conservative (a lower moisture content) than may be expected in many regions of the United States.

Due to the greater variability of the regular gypsum board results, the 95 percent confidence intervals derived from three tests of each of the wood-based panels were mostly or completely within the confidence interval of the 1/2-inch regular gypsum board. The performances of the 5/8-inch hardboard composite, the 3/4-inch mixed species plywood, the 5/8-inch particleboard, and the 3/4-inch southern pine plywood were comparable to the performance of the 1/2-inch regular gypsum board. The performances of the two 5/8-inch untreated plywoods were less than the 1/2-inch gypsum board. The performances of the 5/8-inch FR plywood and 5/8-inch solid wood specimens were between the 1/2-inch gypsum board and the untreated 5/8-inch plywoods.

Continued research is needed to improve methods available to predict analytically the thermal barrier performance of wood-based products. Inability to accurately predict response with the procedures used was due to inadequacies in the theoretical models and an insufficient data base for proper selection of input material properties.

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U.S. Forest Products Laboratory

Wood-Based Paneling as Thermal Barriers, by Robert H. White, Res. Pap. FPL 408, FPL, For. Serv., USDA. 12 p. Madison, Wis.

Fire penetration tests were conducted to examine how the thermal protection afforded insulation in fire-exposed wall assemblies is influenced by wood-based panel type and thickness. This research was conducted only to characterize material response and not to define the more complex performance of full-scale assemblies, but the results do increase our understanding of what panel characteristics influence "finish rating" in assemblies.